Individual Patch Antenna and Antenna Patch Array for Wi-Fi Communication

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Abstract. Wireless communication (Wi-Fi) takes interest, because the wires are cumbersome and generate less free space. This type of communication is widely used among electronic equipments, mainly at home and industry. Patch antennas are very popular due to its characteristics.
The aim of this work is to obtain an efficient and economical patch antenna prototype for indoor and outdoor uses. At first, the prototype of a rectangular patch antenna designed for Wi-Fi, with linear polarization, is presented. After, cuts and grooves were realized on it, in order to improve its gain. The proofs with the individual antenna with four cuts show the feasibility of its use for indoor use.
Subsequently, an antenna array, on the base of the individual rectangular modified patch antenna, was also designed in order to obtain an improved prototype. Proofs demonstrate a good performance of the proposed antenna array for its use for indoors and outdoors as it was expected.

Keywords*:* Gain, linear polarization, cuts, grooves.

1. Problem Description

The implementation of wireless networking, also called Wireless Fidelity (Wi-Fi) or 802.11 networking, is been expanded not only to large size places (airports, coffee shops, libraries or hotels), but also to small places like homes, due to the low-cost internet access provided by this technology, which also supply comfortable workplaces because of wires elimination.

The great demand of Wi-Fi networks has led to the constant search of connectivity improvements; among them has appeared the use of antennas to replace to the original routers antennas, in order to increase substantially the performance, the coverage and the data rate [1].

The gain is another characteristic to improve. The original router antennas of low cost, provide gains from 1,5 up to 2 dBi, in special cases. In fact, in order to increase the coverage some manufacturers of routers sell replacement antennas of high gain [2], for indoors and outdoors [3].

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In addition, to improve the quality and reliability of a wireless link (figure 1a) is necessary the use of antenna diversity, as it is shown in figure 1b.

(a) (b)

Fig. 1. Dimensions Router with (a) a unique antenna ([4]) and (b) with antenna diversity ([5]).

In 1990, under the aegis of IEEE, a group was formed to develop common wireless standards. After the IEEE 802.11 standard was published in 1997, vendors developed Wi-Fi equipment around two variants of the 802.11 standard: 802.11b (operating in 2.4 GHz band) and 802.11a (operating in 5.8 GHz band) by early 2000. Other variants of the 802.11 standard were developed over time, offering higher bandwidth for data transmission [6]. In Mexico, Wi-Fi operates only at 2.4 GHz.

Other alternative to improve the Wi-Fi connectivity is the use of repeaters, which allows extending from 50 m to 20 km. It is reported a network with an enough covering to provide service to an entire city: Paris ([7]), by requiring of fiber optic backbone. It foresees that in the near future, wireless networking may become so widespread that the users can access the Internet just about anywhere at any time [8].

However, Wi-Fi has several limitations. It is prone to interference from other Wi-Fi networks in the vicinity of other devices such as Bluetooth, cordless phones, etc., which operate at the same frequency ranges. Interference degrades network performance and affects reliability.

On the other side, manmade obstacles in the line of sight between the receiving and transmitting antennas have different effects on attenuation and multipath-fading. It is known that overall network performance for 2.4 GHz wireless LANs depends on site environmental situation, which affects decrease the transmission rate.

The aim of this work is to provide alternatives of replacement patch antenna. It is proposed the design and fabrication of a patch antenna prototype for the range of 2.4 GHz that provides a major robustness of the signal for indoor and outdoor communication and with lower cost compared to commercial alternatives.

2. Previous Work

The design of patch antenna is realized in several areas, like GPS communication, cellular telephony, etc ([9]). At commercial level, in the case of Wi-Fi networks, several variants have been implemented in routers, such as the use of patch antennas in antenna arrays (figure 2), or individual replacement patch antennas for indoors and outdoors (figure 3) [3].

Fig. 2. Router with patch antenna [10].

Fig. 3. External patch antenna for outdoors [3].

The elimination of communication wires among computing devices is a critical step toward advanced communication in construction since the dynamics projects site make wires difficult to support [11]. In particular, in the case of patch antennas design to operate at 2.4 GHz, or for multiband applications [9], research works and several patents are been developed [12].

3. Introduction

The concept of microstrip radiators was first proposed by Deschmaps in 1953. A patent was issued in France in 1955 in the name of Gutton and Baissinot. During the 1970s, its development was accelerated by the availability of good substrates with low loss tangent and attractive thermal and mechanical properties, improved photolithographic techniques, and better theoretical models.

However, 20 years passed before practical antennas were fabricated. The first practical antennas were developed by Howell and Munson [13].

At the present time, there are several types of printed antennas in the wireless communications, the most common today is the microstrip or patch antenna, which is fabricated by recording the element pattern of the antenna in a metal piece, commonly cooper, connected to a dielectric substrate with a continuous metal layer connected along the opposed side of the substrate, which forms a ground plane.

The microstrip antennas are relatively inexpensive at its manufacturing and design is not complex. They are frequently used in Ultra High Frequency (UHF) and higher frequencies as the size of an antenna is directly tied to the wavelength at the resonant frequency.

A single patch antenna provides a maximum gain directly from 6 to 9 dB. It is relatively easy to print an array of patches in a single substrate using lithography techniques. An arrangement patch provides much more than a simple patch gain for a small additional cost, and a bigger broadband [14].

The rectangular patch has a simple geometry. When the air is the substrate of the antenna, the length of the rectangular microstrip is approximately half of the wavelength in the free space. As the antenna is loaded with a dielectric substrate, the length of the antenna decreases, while the relative dielectric constant of the substrate increases.

An inherent advantage of the patch antennas is the ability to have diversity of polarization. They can be easily designed to have Vertical, Horizontal, Circular Right Hand (RHCP) or circular Left Hand (LHCP) polarizations, by means of using of multiple feed points or a single one. This property allows patch antennas to be used in several communication areas, such as in the design of personal communication equipment [15].

In this work, we presented the design and fabrication of prototypes of an individual rectangular antenna and of antenna array for 2.4 GHz. The tests for sending-receiving signals using the patch antenna prototypes are realized in order to know their performance.

4. Rectangular Patch Antenna Design

The parameters to be considered in the design of a patch antenna are shown in Figure 4, they are:

- Operation frequency (f_o).
- Dielectric constant of the substrate (ε_r).
- Height, h (or thickness, t) of substrate.

Fig. 4. Dimensions of a rectangular patch antenna.

With these parameters, the patch dimensions can be calculated using the following equations [13, 16-17]:

For the patch width:

$$W = \frac{c}{2 f_0 \sqrt{\frac{\varepsilon_r + 1}{2}}} \tag{1}$$

Where: c = Constant speed of light in vacuum, ε_r = Dielectric constant substrate and f_0 = Operating frequency.

The effective length is calculated using:

$$L_{eff} = \frac{c}{2 f_0 \sqrt{\varepsilon_{reff}}} \tag{2}$$

where the effective dielectric constant, ε_{eff}, due to the influence of the metal patch, was obtained from:

$$\varepsilon_{reff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left(1 + 12\frac{h}{W}\right)^{-1/2}, \text{ if } \frac{W}{h} > 1 \tag{3}$$

The two increments in the length, which are generated by the fringing fields, making electrical length lightly larger than the physical length of the patch:

$$\Delta L = 0.412h \frac{\left(\varepsilon_{reff} + 0.3\right)\left(\frac{W}{h} + 0.264\right)}{\left(\varepsilon_{reff} - 0.258\right)\left(\frac{W}{h} + 0.8\right)} \tag{4}$$

The patch length is given by:

$$L = L_{eff} - 2\Delta L \tag{5}$$

The length and width of ground plane (and the substrate), L_g and W_g, are [13]:

$$L_g = 6h + L \tag{6}$$

$$W_g = 6h + W \tag{7}$$

To improve the performance of the rectangular patch, it is possible to make changes in its geometry, such as cuts and grooves.

Using 2.4 GHz as the operation frequency, and 1.6 mm as the width of FR-4 PCBs plates; the corresponding sizes of the rectangular patch antenna are presented in Table 1. The feed point location is (-0.005 m, 0), considering the center of the patch as the coordinates origin.

Table 1. Dimensions of the rectangular patch antenna.

	FR-4		
Dimensions	**X** **W (m)**	**Y** **L (m)**	**Z** **h (m)**
Patch	0.0395	0.0308	
Substrate	0.049	0.0404	0.0016

The next step is entering data into appropriate software. We use FEKO, which offers several tools for the patch antenna simulation, and has very friendly environments.

5. Comparison of the Rectangular Geometries

The rectangular patch antenna designs were realized considering different geometries. Cuts and grooves on the rectangular patch were implemented in order to improve its performance, basically its gain. In figure 5, 4 antennas geometries are shown.

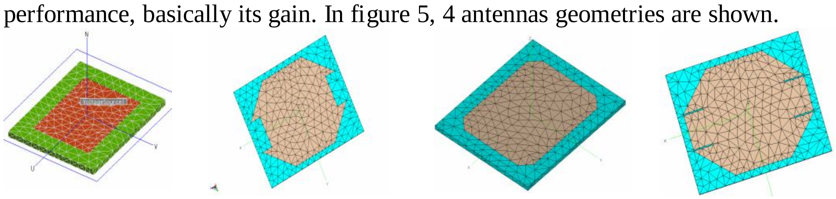


Fig. 5. Implemented geometries: rectangular, rectangular with 2 and 4 grooves combined with cuts and rectangular with small cuts in the four patch corners.

Grooves and cuts performed on rectangular patch antenna geometry allow us to determine the electric and magnetic field operation modes and to increase the gain, respectively. When we make cuts, is necessary to be careful with its size and its number. The cuts not only increase our gain, they can also modify other parameters. The first parameter that is necessary to verify when we perform a cut is the central operation frequency, because when we increase the cut depth, the surface of the patch diminishes and the distribution of currents is modified. Then, it is necessary to relocate the feeding point. Under critical cases, it is necessary to redesign all again.

In table 2, it is shown the corresponding gain values to each antenna. As can be seen, the biggest gain was obtained with the rectangular geometry with cuts. For this reason, the prototype was realized using this geometry.

Table 2. Geometries and theirs corresponding gains.

Geometry	***Rectangular***	***2 grooves and cuts***	***4 groves and cuts***	***Small cuts***
Gain (dB)	3.05	3.28	3.11	3.9

The fabrication of rectangular patch antenna, with small cuts is easy to realize by means of PCBs templates.

6. Individual Antenna Design

The basic characteristics of final design of the modified rectangular patch antenna are:

- Operation frequency: 2.4 GHz
- Substrate material: FR-4, double layer plate of 30 cm x 20 cm
- Patch and ground plane material: Cooper
- Feeding: coaxial cable of 50 ohms
- Patch sizes: 49.12 mm x 40.46 mm x 1.6 mm
- Cuts depth: 1/8 of wavelength
- Polarization: linear
- Gain: 3.91 to 4.04 dB for the frequency range from 2.4 up to 2.45 GHz (Figure 6)
- Beam width: 90 degrees (Figure 7)

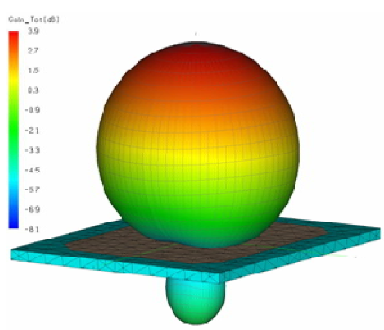


Fig. 6. Gain of the individual antenna.

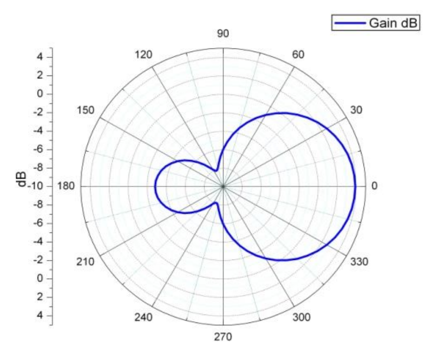


Fig. 7. Beam width of patch antenna.

The antenna directivity and the corresponding far electric field are shown in figures 8 and 9. The peak of the electric field is located at 2.41 GHz. The simulated results fit the design requirements. The chosen design is very simple and it is possible to develop under low fabrication cost due to the employed method.

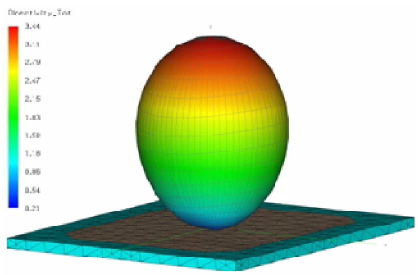


Fig. 8. Directivity of individual indoor antenna.

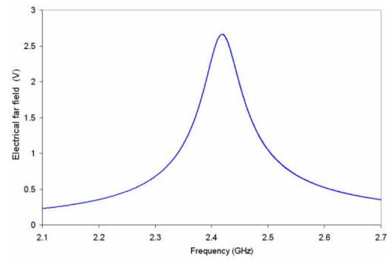


Fig. 9. Simulations results of emitted electric field.

The calculated characteristic impedance is of 7.72 Ω, using equation 8 [16], which is very near to the value obtained from simulation, 6.2 Ω, (figure 10), at the central frequency.

$$Z_0 = \frac{120\pi \times h}{W\sqrt{\varepsilon_{eff}}} \tag{8}$$

The simulated impedance considering a 50 Ω load is presented in figure 11. At 2.41 GHz, the impedance value is 60.51 Ω.

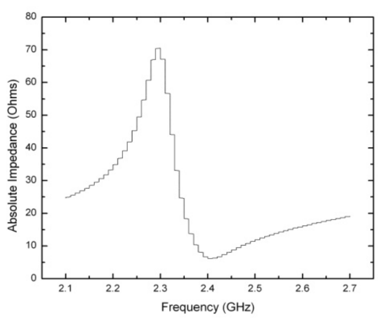


Fig. 10. Impedance of the individual antenna.

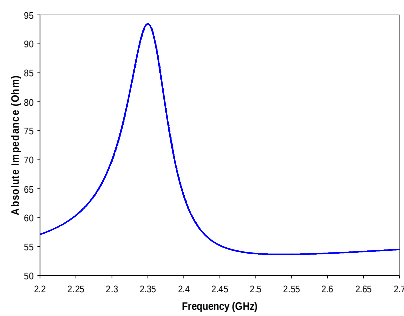


Fig. 11. Impedance of the individual antenna whit a 50 Ω load.

7. Individual Antenna Prototype

The final prototype was realized including a female BNC connector. The first step is to make the silkscreen on the PCBs plate, on both sides. On the used board is possible to obtain 9 antennas. The serigraphy technique produce that not all antennas have a good quality. Better results are obtained with commercial printing, but the costs are increased.

After removed the cooper excess, we cut each antenna and accomplish the drilling for the connection of their corresponding feeding points. In figure 12, two individual antennas are shown with its corresponding feed point welded to the BNC connector. This type of connector was chosen for compatibility with the laboratory equipment.

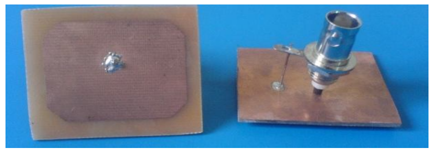


Fig. 12. Individual patch antenna prototype.

A detailed analysis of materials selection was considered. Their frequency response and availability were also taken into account.

8. Experimental Results

After, the prototype fabrication, the corresponding tests are realized to determine the experimental operation frequency and the connection quality achieved with its use. The tests were realized inside and outside of CIICAp building, shown in figure 13.

(a) (b) (c)

Fig. 13. a) Façade b) interior and c) exterior (here is located the Photonics Lab.).

The tests were realized by using a signal generator and a spectrum analyzer, with antenna prototypes coupled by means of coaxial cables to their exit and entrance, respectively (see Figure 14). The distance between the antennas was of 6 cm.

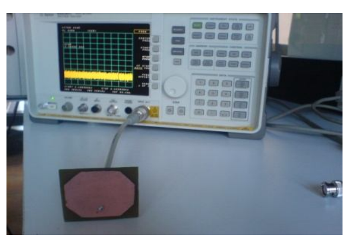


Fig. 14. Patch antenna coupled to the spectrum analyzer.

In order to verify the operation frequency range, a sweeping of frequency from 250 MHz up to 10 GHz was made. Figure 15, shows the obtained values of the received power. As can be seen, the highest received power occurs in the frequency range from 2 to 3 GHz. An enlargement corresponding to the frequency range from 2.2 to 2.8 GHz is presented in figure 16. As can be seen, the peak frequency corresponds to the range from 2.4 to 2.45 GHz, in accordance with the corresponding design requirement and simulation (see figure 9).

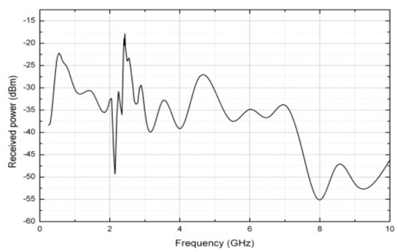


Fig. 15. Received power on the frequency range from 250 MHz to 10 GHz.

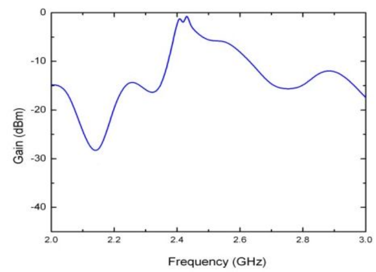


Fig. 16. Normalized received power on the frequency from 2.2 GHz to 2.8 GHz.

After the experimental establishment of the central frequency, we made a comparison with a commercial antenna performance. To determinate the quality of sending/receiving signals, we used two Wi-Fi similar routers, in one of them, we replaced its antennas with our prototypes (figure 17). Figure 18 shows the received power inside and outside of the CIICAp building, using a laptop as reference.

The signal "ciicap" is the name of the router with the commercial antennas and "alecita", the router with the antenna prototypes. As can be seen, outside the CIICAp building, the transmission/reception is better using "ciicap", but inside, the signal is stronger with "alecita". Therefore, it can be concluded that this individual prototype shows an excellent performance for indoors.

Fig. 17. Patch antenna coupled to the router.

(a) (b)

Fig. 18. The received power (a) outside and (b) inside of the CIICAp building using individual antennas.

After, finished the first part of this work, we also designed an antenna array, in order to increase the obtained gain, and to obtain a prototype for outdoors. This approximation is presented in the following sections.

9. Antenna Array

In order to improve the reception outside of the building, we design an antenna array connected by microstrip lines. The length of the microstrip lines corresponds to $\lambda_g/8$ (figure 19), that is, 8 mm and a width of 2 mm. The impedance of the microstrip, obtained from tables [16] is approximately 60 Ω.

The maximum gain is 4.4 dB (figure 20). The beamwidth was reduced to 80 degrees (figure 20), as it was expected, while, the directivity is increased from 3.44, for the case of individual antenna, to 4.47 for the array (figure 22). The corresponding prototype is shown in figure 23.

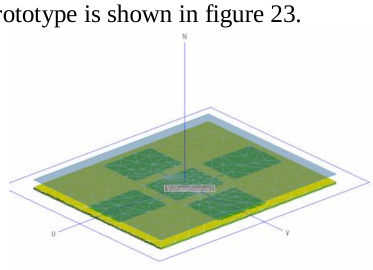


Fig. 19. Antenna array.

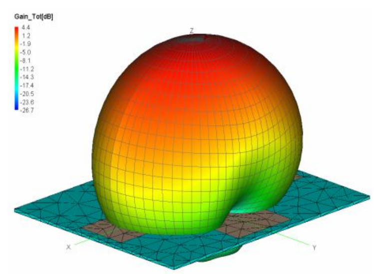


Fig. 20. Gain of the antenna array.

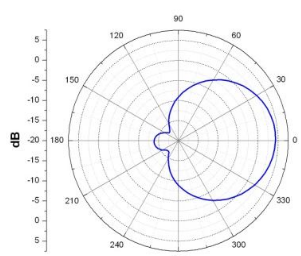


Fig. 21. Beamwidth of the antenna array

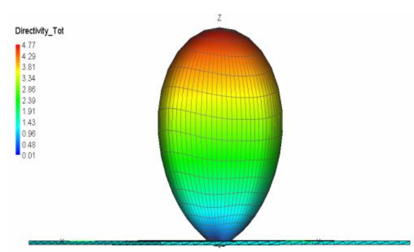


Fig. 22. Directivity of the antenna array.

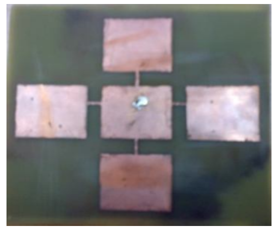


Fig. 23. Prototype of antenna array coupled by microstrip lines.

It must be mention that the simulated gain, considering arranges of rectangular with small cuts shape of the antenna components was of 5 dB, lightly greater than for the case of the rectangular ones, but until now it was not fabricated.

10. Experimental Results of the Antenna Array

The simulated electric field showed a peak in 2.44 GHz (figure 24), lightly displaced to the proposed central frequency.

The normalized results of the experimental measurements, with a signal generator and a spectrum analyzer, are shown in figure 25. The frequency range, where there is a good response, is from 2.445 up to 2.65 GHz.

The more representative measurements of the received signal, using a laptop, are shown in figure 26.

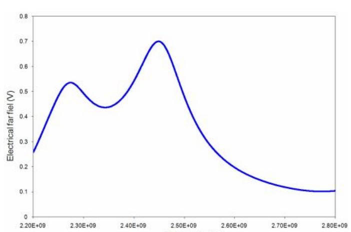


Fig. 24. Simulations results of emitted electric field.

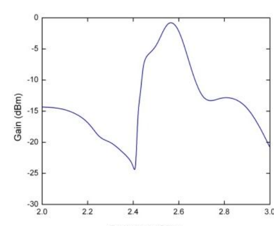
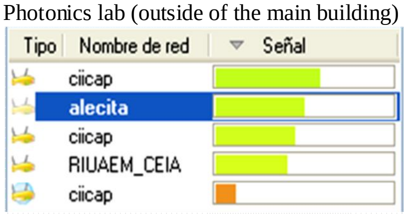


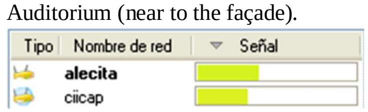
Fig. 25. Normalized experimental received power.

Photonics lab (outside of the main building)

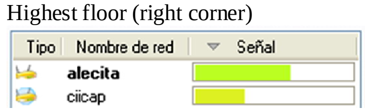


(a)

Auditorium (near to the façade).



Highest floor (right corner)



(b)

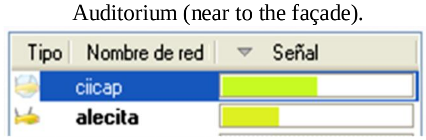
Fig. 26. The received power (a) outside and (b) inside of the CIICAp building using antenna arrays.

As can be seen, with the antenna array prototypes we obtained a very good response not only inside, but also an acceptable robustness outside of the CIICAp building, which was the aim of this design.

In order to compare the performance of the router used to replace the antennas, against its performance considering its original antennas, see “alecita” signal figure 27.

Photonics lab (outside of the main building)

Auditorium (near to the façade).



(a) (b)

Fig. 27. The received power (a) outside and (b) inside of the CIICAp building, with the router used in figure 26, but with its original antennas.

As can be appreciated from figures 26 and 27, the router with the antenna prototypes has better reception in both cases, inside and outside of the building, compared with its performance using its commercial integrated antennas.

11. Economic Profit

The high range routers, with antenna diversity, have very high costs, since 100 Euros [18]. The high prices create the necessity to improve the range of conventional routers. Replacements of antennas are offered in the market to achieve this aim. Their costs vary from approximately $50 dlls, offered by routers manufactures, to approximately $30 dlls, offered by exclusive antennas manufacturers, as alternatives of low cost [19]. The current price of patch antennas with 9 dBi gains goes from 58 up to 104 pounds [20] (see figure 28).

Fig. 28. Commercial external patch antenna.

In this work, without considering the costs of the used equipment, the devoted time, and the profit margin, the fabrication net cost of individual antenna prototypes is approximately of $150 Mexican pesos for each required antenna, considering also the acrylonitrile butadiene styrene ABS cover, which is suggested for commercial presentation of our prototype.

In the case of the antenna array the cost would be substantially increase due to the ABS cover, not for the substrate cost, then other material cover alternative must be analyze.

The prices can be drastically reduced if a great scale fabrication is considered. In the case of the antenna arranges, the prices would be lightly increased, specially, due to the cover costs.

12. Conclusions

The best response for the two cases (individual antenna and array) was obtained only using cuts, with $\lambda_g/8$ deep length. For the antenna array, the length of the microstrip lines also corresponds to this value. Simulation results show a minor back radiation in the case of the antenna arrays and a lightly narrower directivity that in the case of the individual antenna, as it was expected.

The proofs permit to observe the prototype performance, which show lightly differences to the simulation results, considering the corresponding loads. The possible sources of these deviations can be: the precision of the fabrication process, the feed point has small dimensions in the prototype as well as the feed line. On the other hand, the coupling and the propagation medium also produce additional losses.

The prototype of individual patch antenna shows a good performance for sending/receiving signals in the range used by indoor Wi-Fi communications, also in presence of obstacles like walls and in absence of line of sight, whereas the antenna array coupled by microstrip lines shows a better outdoor performance.

The antenna array shows a good performance inside and outside of the CIICAp main building.

The fabrication of the prototypes has relatively a very low cost, which makes their use feasible for commercial applications. But, in order to have a competitive product it is necessary to reduce the antenna array sizes and to increase the gain. Therefore, it is necessary to analyze the possibility to use other materials and other fabrication processes.

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